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This report describes methods for evaluating the resistance of personnel armor material to perforation by attacking projectile fragments, simulated fragments, and small arms ammunition. It covers physical characteristics of materials, firing tests for ballistic limits of materials, determination of residual velocities, and environmental conditioning. This is not applicable to material in actual armor configuration.

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U. S. ARMY TEST AND EVALUATION COMMAND
DEVELOPMENT TEST II (EP) - COMMON TEST OPERATIONS PROCEDURES

AMSTE-RP-702-109
*Test Operations Procedure 10-2-506 — 6 January 1975

BALLISTIC TESTING OF PERSONNEL ARMOR MATERIALS

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SECTION I
GENERAL

1. Purpose and Scope. This TOP describes methods of evaluating the resistance of the material used in personnel armor to penetration by projectile fragments, simulated fragments, and small arms ammunition.

2. Background. Personnel armor is designed to protect the wearer against injury from small fragments generated by exploding munitions and, when specified, from small arms fire. It may be made from a variety of materials including metals, textiles, plastics, and ceramics. Personnel armor includes items such as helmets, armor vests, face shields, torso shield, leg armor, and protective suits. It is relatively light in weight, usually between 1/4 and 4 pounds per square foot, but may be heavier if it is to provide protection against small arms fire.

*This TOP supersedes MTP 10-2-506, 4 October 1968.

Materials are submitted as flat sections to facilitate testing, but they may be furnished as helmets, armor vests, etc., when required for specific tests. These materials are given laboratory tests for hardness, strength, elongation, and other physical characteristics. To determine ballistic protection, they must be subjected to resistance-to-penetration tests with appropriate missiles.

Some tests, particularly ballistic acceptance tests, are conducted to determine the ability of material to prevent perforation (i.e., complete penetration) by the attacking projectile or fragment. Such tests are covered by paragraphs 6, 7, and 8. Other tests are conducted not only to determine the ability of material to prevent perforations, but also to determine the velocity that remains when an attacking fragment does perforate the armor. This test, which provides lethality data that can be equated to bodily injury, is covered in paragraph 5.

3. Equipment and Facilities. Equipment and facilities are described under the individual test procedures below.

SECTION II
TEST PROCEDURES

4. Preliminary Activities.

4.1 Pretest Data Review. The test engineer should study the results of past firings of similar tests in order to make an estimate of the ballistic properties of the test item and to detect any gross errors in the testing techniques.

4.2 Physical Characteristics of Test Materials. The following information is obtained and recorded for each armor item to be tested:

a. Manufacturer.

b. Weight (nearest 0.01 ounce per square foot).

c. Average thickness of area fired upon (nearest 0.001 inch).

d. Full description of each layer if material is composite armor.

e. Bonding technique (when applicable).

4.3 Laboratory Properties of Test Materials. The following properties of test materials are obtained either from the manufacturer's laboratory data or from tests made in-house (TOP's 3-2-806, 3-2-807 and 1-2-504).

a. Metals - Commercial designation, hardness, tensile strength, yield strength, elongation, impact toughness, alloy type, composition.

b. Plastics - Commercial type, configuration, hardness, brittleness, elongation, water absorption.

c. Textiles - Commercial type, fiber size, type and density of weave, strength, water absorption.

d. Ceramics - Commercial type, brittleness.

e. Composites and laminates - Properties of individual layers.

5. Determining Residual Velocities: The V_S-V_R Curve.

5.1 Objective. To obtain quantitative measures of the ability of body armor materials to completely stop or reduce the velocity (therefore lethality) of attacking fragments of various velocities. To accomplish this, fragments are fired from weapons over a range of velocities, and the residual velocity (fragment velocity remaining after a complete penetration of the armor) of each is measured. The results are presented graphically as a V_S-V_R (striking velocity versus residual velocity) curve.

5.2 Method. A detailed treatment of this method is given in reference 5 (appendix).

5.2 Fragments. The fragments used in this test are actual shell fragments recovered from static detonations of HE projectiles, especially mortar shell and foreign ammunition. A soft recovery technique, generally using wallboard which will not damage the fragments, must be used. TOP/MTP 4-2-813 describes a method for recovering a small portion of the main spray. To recover all of the main spray would require wallboard to be stacked all around the sides of the projectile at an appropriate standoff. Each recovered fragment is weighed, and those of 2, 4, 8, 16, 20, 24, 40, and 64 grains are grouped. In any group, weight tolerances of (±) 2 to 3 percent are preferred but should not exceed (±) 5 percent. Each fragment to be fired is geometrically characterized by measuring the presented area in 16 different orientations (i.e., the 16 nonopposing faces of an icosahedron, which is a polyhedron formed with 20 equilateral triangles). The 16 areas are averaged to form $\bar{A}$ which is an important factor in connection with air drag and retardation by armor materials. The parameter K, the average shape factor of the fragment, is defined as

$$K = \frac{m}{\sqrt{\bar{A}^3}} .$$

where m is the mass of the fragment. The fragment to be fired is mounted in a sabot as described below.

5.2.2 Velocity Measurement Techniques. The two methods employed to measure fragment velocities are (a) the flash X-ray method (figs. 1 and 2) which should be used when the target may break up, such as during the

testing of metallic or hard-faced composites; and (b) the chronograph, break-screen (or lumiline screen) method (figs. 3 and 4) which is generally used when nonmetallic or fabric-type targets are to be tested. The break screens shown in figure 1 are used to trigger the X-ray tubes and chronograph. Flash X-ray (radiographic) techniques in general are covered in TOP/MTP 4-2-825 with specific information on velocity measurements in TOP 2-2-710. Chronographic techniques are described in TOP/MTP 4-2-805. Velocity measurements of fragments require that special drag coefficients be obtained from appropriate sources. Gun-to-target distances will vary. They may be as little as 52 inches (fig. 1) for very small fragments fired at body armor; for the larger fragments greater distances are used.

5.2.3 Facilities. In addition to velocity measuring equipment, the following facilities are required:

a. Smooth bore weapon. The caliber is determined by the size and weight of the fragment and velocity range to be explored. A caliber 0.540, smooth-bore, Mann barrel is suitable for launching fragments of 2 to 70 grains.

b. Sabot. The sabot material is usually a type of plastic (linen-base phenolic, lexan, etc.), with the design, diameter, and length determined by the weight and shape of the projectile fragment. The fragment is held in position on the sabot with paste or a nonhardening adhesive. Reference 4d (appendix) describes firing with a sabot. A teflon pusher is placed behind the sabot to act as an obturator.

c. Sabot stripper or tipping device. The standard stripper screwed to the gun muzzle or the NRL (Naval Research Lab) tipper device is necessary to separate the fragment from the sabot. (See also ref. 4b, appendix.) A sabot-discarding aid is also used. This is a steel deflector plate, 1/4-inch minimum thickness, with a 1- to 1-1/4-inch diameter hole aligned with the center of the gun bore, located between the gun muzzle and the first break screen.

d. Velocity break screen. A 4- by 6-1/4-inch (minimum) manifold paper with silver circuit grid, line space and width determined by fragment size, is located both in front of and behind the target to initiate velocity measuring instrumentation.

e. Yaw cards. These consist of double weight, color print photographic paper located within 1 inch in front of the target. They show the presented area of fragments at impact.

f. Witness material. Gypsum wallboard, 1/2-inch thick, is used to catch residual fragments, which are recovered for analytical purposes.

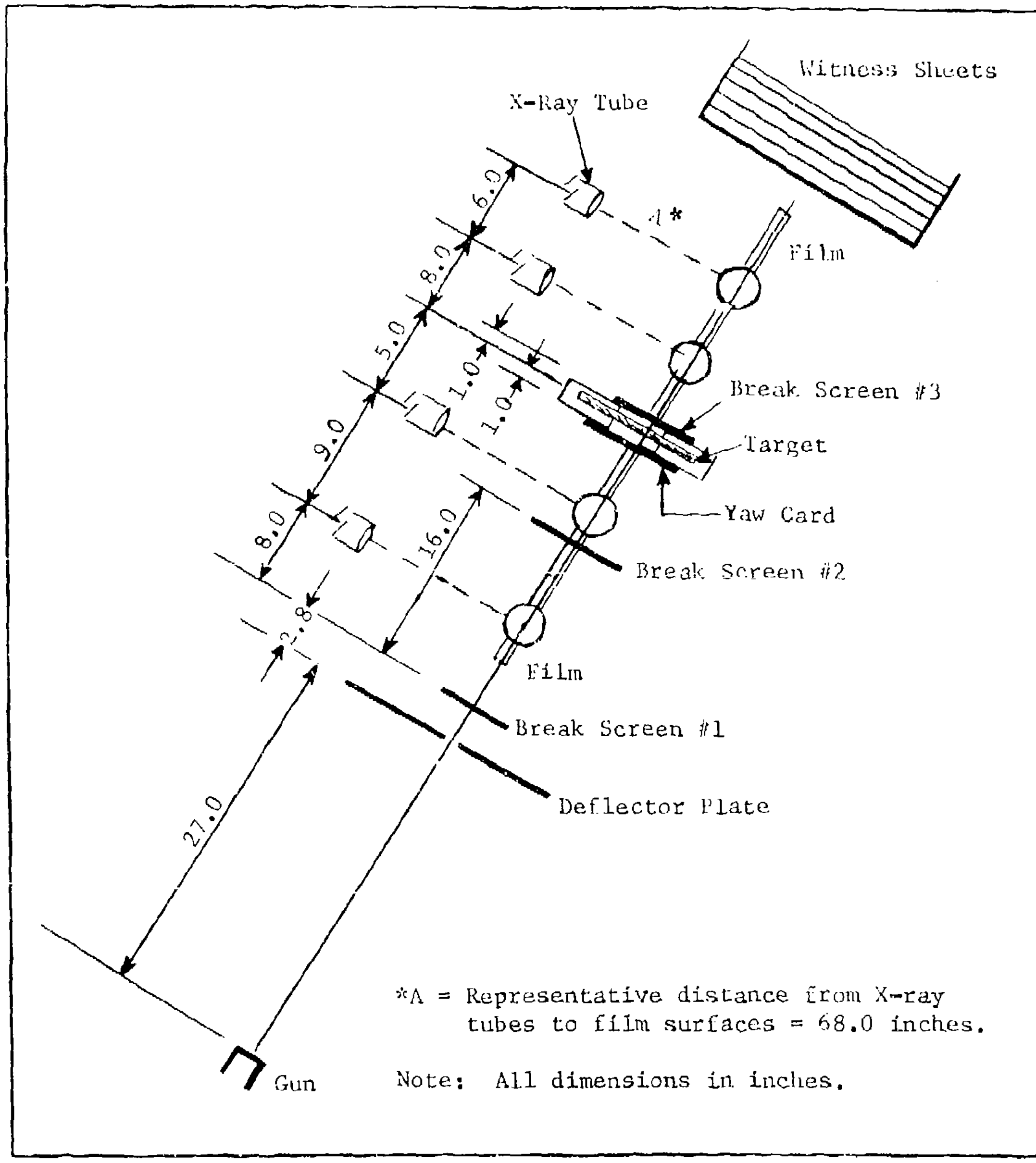

Figure 1. Schematic Diagram Showing Flash X-Ray Units Set Up to Measure Striking and Residual Velocities in Test of Body Armor with 2- to 70-Grain Fragments.

Figure 2. Interior of Testing Chamber Showing Four Pairs of X-Ray Tubes (X_1, X_2, X_3, and X_4) Aligned With Path of Fragment Through Deflector Plate (P), Target (T), and Witness Material (W).

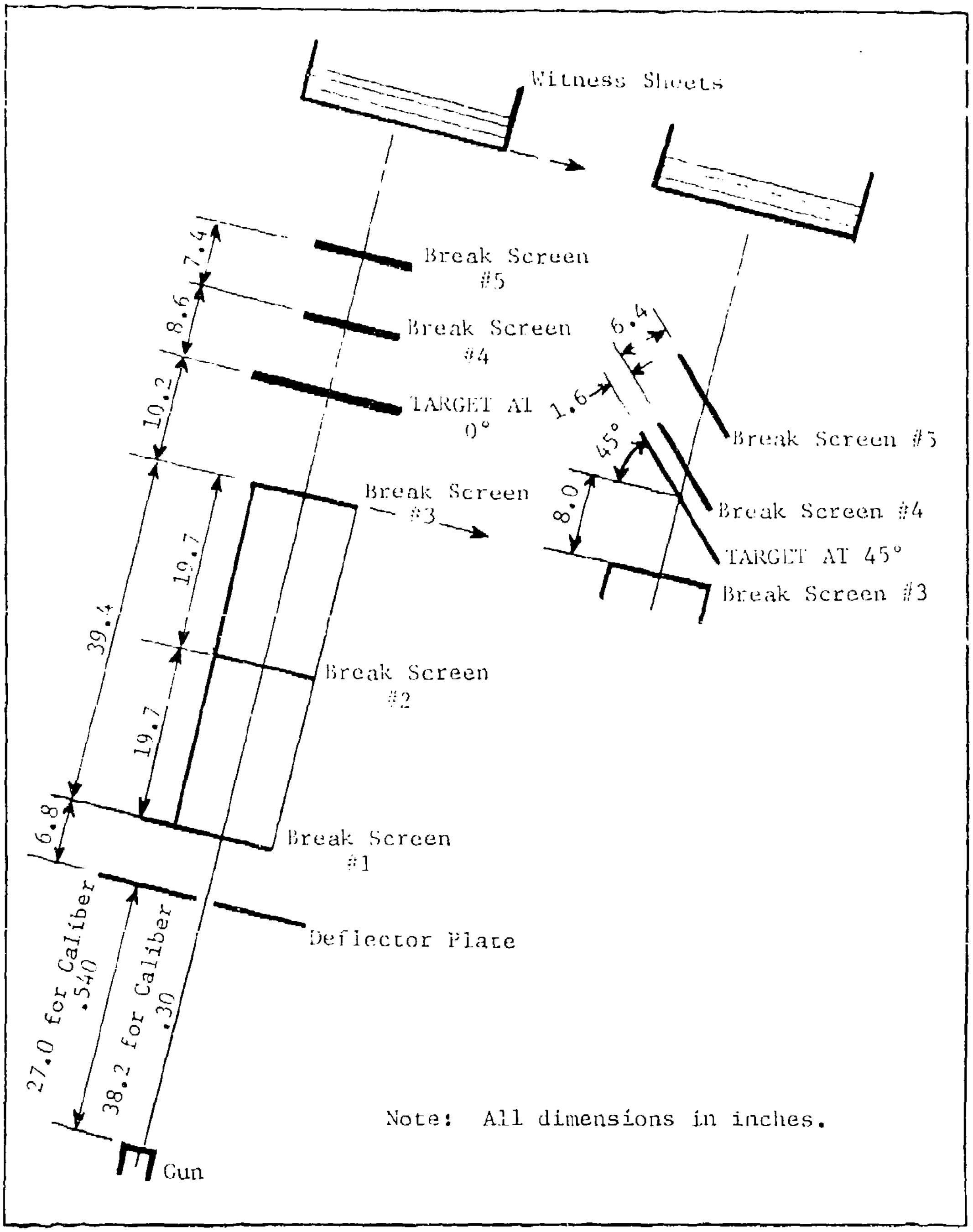

Figure 3. Break Screen Arrangement for Measuring Striking and Residual Velocities in Tests of Body Armor at 0° and 45° Obliquities With Fragments Under 70 Grains.

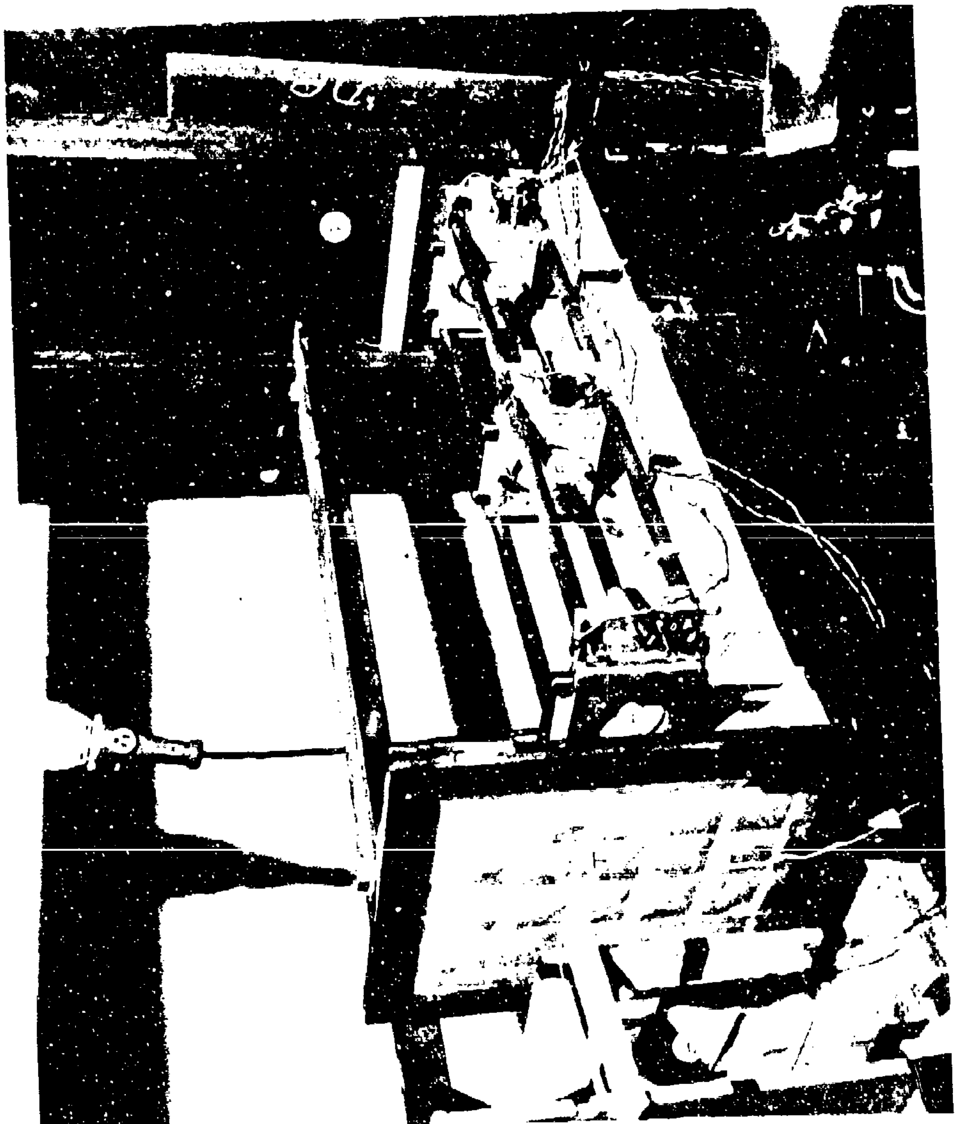

Figure 4. View of Deflector Plate (P), Three Break Screens (F) in Front of Target (T), and One of Two Break Screens (B) that are Located Behind Target.

5.2.4 Firing Procedure. This procedure is generally in conformance with reference 5 (appendix).

The first step is to acquire data for estimating the "limiting velocity" (V_L). The V_L is the same as the V-0 ballistic limit; that is, the highest striking velocity at which the probability of a complete penetration is zero. At the V_L, the residual velocity (V_R) will be zero since the fragment will just get through the target with no remaining velocity. As the fragment velocity is increased, perforations will begin to occur and residual velocities will increase.

The V_L is estimated graphically. One method that has been used is as follows: From previous work an estimate is made of the velocity 500 fps above the V_L. A propellant charge is chosen that will produce this velocity for the fragment to be fired. The V_R of this round and of all other complete penetration rounds is recorded. If a complete penetration occurs, the velocity for subsequent rounds is reduced by approximately 200-fps intervals until a partial penetration occurs. If a partial penetration occurs on the second round fired, the velocity is increased in 200-fps intervals on the next two rounds. If a partial penetration occurs on the third round, the velocity is increased by 200 fps on the next round. In any event, three complete penetrations are required, and, if necessary, additional rounds at 200-fps higher velocities are fired to obtain them. An initial estimate of the V_L can be made after three or four complete penetrations have been obtained, provided that one shows very little residual velocity or a partial penetration was also obtained.

To estimate the V_L, V_R versus V_S (striking velocity) is plotted and extrapolated to V_L, where $V_R = 0$. Figure 5 illustrates typical results and an extrapolation. Note that the extrapolation is curvilinear thereby giving the curve the appearance of a knee. This shape has been noted to occur on many tests of this type, and should be assumed.

The test plan applying the above method called for verifying the V_L by determining a V50 ballistic limit using the technique of paragraph 7, except that the ballistic limit was based upon four complete penetrations and four partial penetrations within 125 fps. The V50 ballistic limit should always be at a higher velocity than the V_L. If results show V50 lower than V_L, the V_L is re-estimated. Confirming rounds are fired if necessary.

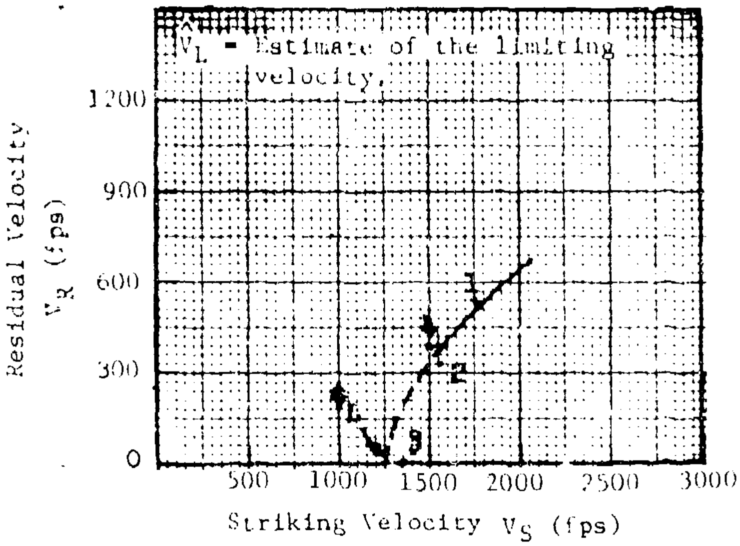

Figure 5. Estimate of Limiting Velocity.

To develop a complete V_R versus V_S curve, ratios of V_S: V_L ranging from 1.00 to 4.00 (in the above case) are set up to determine which striking velocities should be used. The following is a suitable selection of striking velocities.

Approximate Striking Velocity, V_S
1.00 V_L
1.06 V_L
1.12 V_L
1.19 V_L
1.26 V_L
1.34 V_L
1.42 V_L
1.68 V_L
2.25 V_L
3.00 V_L
4.00 V_L

Earlier firing will have been close enough to some of these values to be acceptable, and need not be repeated. Figure 6 shows the results of a complete firing program. If firing is to be limited, firings in the range of 1.0 to 1.5 V_L should be given preference.

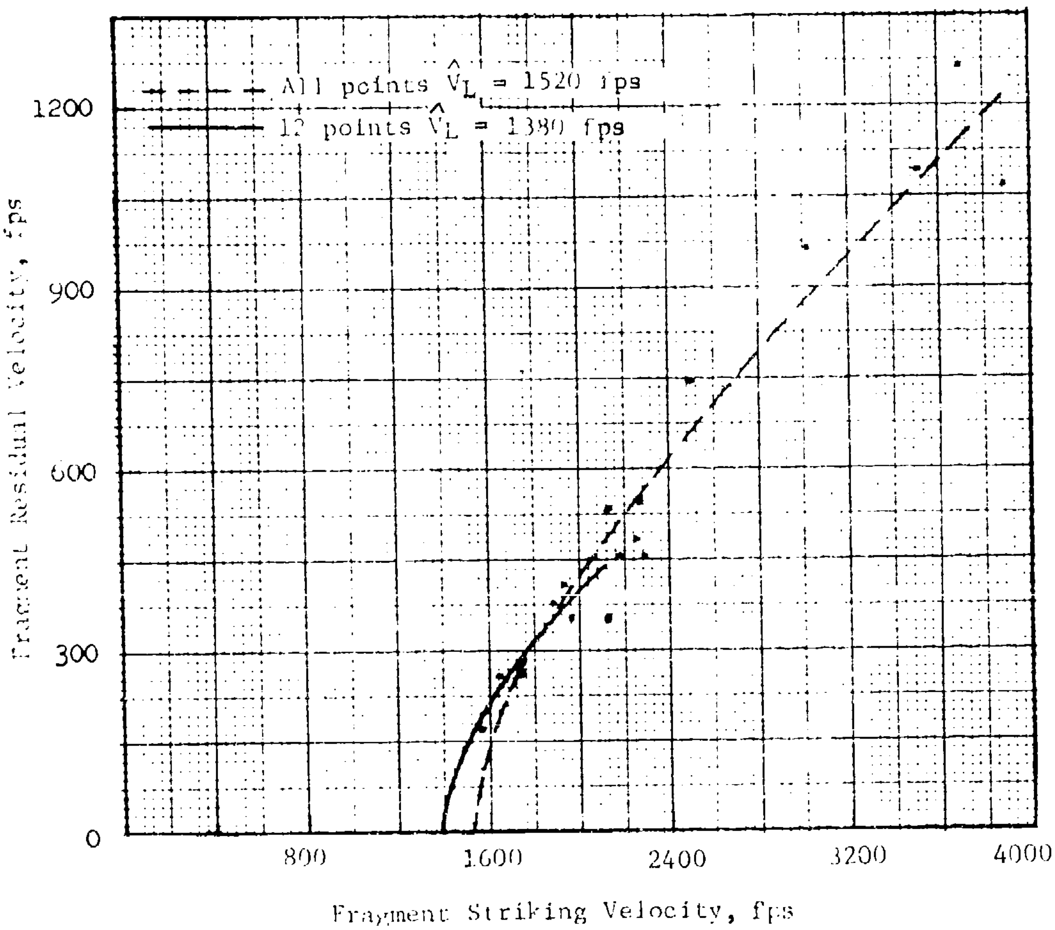

Figure 6. Representative V_S-V_R Curve for a Specific Fragment Mass-Target Material Combination Showing Faulty Curve Generated by Insufficient Data as Contrasted to True Curve.

5.2.5 Data Required. The data to be obtained from tests of this type are specified by the sponsoring agency and generally include, but are not limited to, the following:

a. Protection ballistic limit of target-fragment combination.

b. Striking velocity of fragment.

c. Fragment presented area just before target impact.

d. Residual velocity of major fragment or fragments.

e. Limiting velocity of each fragment-target combination.

f. Target thickness, areal density, etc.

g. Fragment weight, length, width, thickness, and average shape factor prior to firing.

6. Determining V50 Ballistic Limit with Simulated Fragments.

6.1 Objective. To evaluate the resistance of personnel armor materials to attack from hardened steel configurations that are designed to simulate fragments.

6.1.1 Advantages. This test method has the following advantages over other fragment tests:

a. Missiles of consistent weight, shape, and properties are used, permitting consistency of test conditions.

b. Missiles can be mass produced and are relatively cheap.

c. Precise velocity control is easily achieved.

d. Small targets and modest range facilities are possible.

6.1.2 Disadvantages. In the opinion of many investigators, the fragment simulators do not simulate fragments adequately. While they can screen materials, fragment simulators cannot show what the performance of a target will be against actual fragments launched by projectile detonations.

6.2 Method.

6.2.1 Types of Simulated Fragments. There are basically two types of simulated fragments.

a. A standard fragment-simulating (FS) projectile that is a widely used, specific type of solid steel projectile available in different weights.

b. Various other geometric shapes most of which require sabots for launching.

Standard FS projectiles (fig. 7) are homologous in shape; produced in sizes of cal .22 (17 grains), cal .30 (44 grains), cal .50 (207 grains), and 20-mm (830 grains); and procured under MIL-P-46593A(ORD). The FS projectile is an attempt to produce fragments that are standardized and do not require a sabot for firing. It was expressly developed for evaluating the fragment resistance of development body armor and lightweight aircraft and vehicle armor. FS projectiles are also employed in the acceptance testing of body armor. Cubes, suitable for mounting in

sabots, have also been standardized and are procurable under MIL-P-46125 (MR). Cylinders, parallelepipeds, darts, and spheres have also been used. Some of these are shown in TOP 2-2-722.

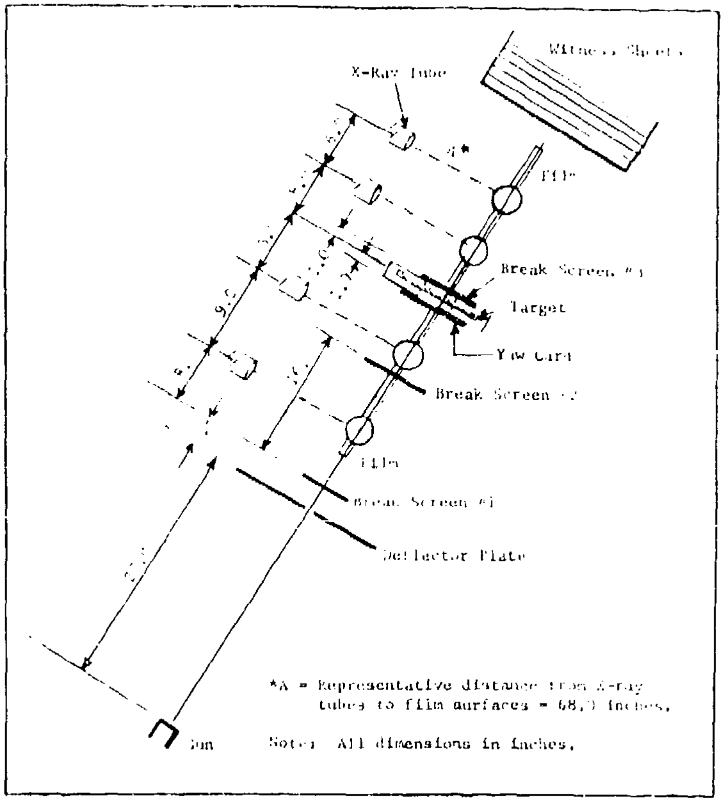

Figure 7. Fragment-Simulating Projectiles Used to Evaluate Personnel Armor.

6.2.2 Characteristics of Impacts by Fragment Simulators. The orientation of the fragment simulator upon impact with armor has a considerable effect upon the efficiency of penetration and is a factor in the scatter of data. A cube, for example, hitting on a corner will penetrate more easily than if it hits on one of its flat sides. This is not a problem with FS projectiles when fired at a 0° obliquity target, but does become a factor with oblique targets because penetration is less efficient if the projectile strikes on a tapered portion of its nose rather than on an untapered portion. Right circular cylinders do not have this disadvantage at obliquities while retaining the advantage of not requiring sabots. A major disadvantage of cylinders is the sparsity of data concerning them for use in comparisons with materials tested in the past. Spheres, of course, provide perfect consistency of impact orientation, but their use is not recommended because of their marked dissimilarity to fragments.

The vast majority of tests with fragment simulators employ the standard FS projectile for several reasons: there is a large amount of past data available involving them; they are readily available in several weights, relatively inexpensive to fire, and they reasonably simulate fragments. Thus, much body armor testing is performed with FS projectiles.

6.2.3 Types of Tests. The type of test conducted is dependent upon the resources (funds and target area) available, the objective of the test program, and the specification, if applicable.

a. The traditional test program involves obtaining a 10-round, V50 protection ballistic limit using the up-and-down firing technique (TOP 2-2-710). The ballistic limit is, then, the average of 10 striking velocities: the five highest partial penetrations and the five lowest complete penetrations occurring within a velocity spread of 125 fps. If a ballistic limit is not reached within a spread of 125 fps, a 14-shot ballistic limit with a spread of 150 fps is acceptable.

b. A second testing method follows the Langlie sampling technique (TOP 2-2-710) which generally involves 12 to 16 firings, produces a standard deviation as well as a V50 ballistic limit, and is suitable for comparing types of materials. This is the minimum test that should be used for comparing materials.

c. A third method, and one that is more desirable for comparing development materials than either of the above, is to obtain three V50, 10-round ballistic limits for each target.

d. Occasionally, a fourth method is employed when there is a need to obtain a very precise measurement of the ballistic limit and its standard deviation. In this case, the Probit method (see TOP 2-2-710) is preferred, with perhaps 50 to 200 fragment simulators fired, composed of groups of 8 to 15 fired at each of 6 to 15 velocities that cover the range from V-0 to V-100.

In firing, a gun-to-target distance of 16 feet is considered standard for body armor, with two lumiline screens spaced about 3 feet apart for velocity measurements. (Special tests may have shorter distances as illustrated in para 5.) A complete penetration is defined by the "protection" criterion; that is, an impact that results in either a portion of the plate or fragment moving behind the plate with sufficient energy to perforate a witness sheet of 0.020-inch aluminum 2024-T3 or T4 placed about 6 inches behind the armor. Fragment velocities are controlled as usual by varying the weight of propellant. In doing so, however, the varying weights of the combined weight of sabot plus fragment must be considered. When applicable, a yaw card is placed just in front of the target to indicate impact orientations. If residual velocities are required, they are obtained as specified in paragraph 5.

6.3 Data Required. All data pertinent to the armor material are recorded as indicated in paragraph 4. The exact obliquity of the armor and the striking velocity of each partial and complete penetration are recorded. (As required by the directive, residual velocity of the fragment after it passes through the armor, and velocity, size, and distribution of the fragments displaced from the target may be recorded as in para 5.2.) Impact orientations are described when pertinent.

6.4 Analytical Plan. The analysis technique depends upon the method of testing employed and the criterion statement. In most cases the objective is to determine which of two or more materials provides the highest resistance to penetration. If two or more V50 ballistic limits have been obtained on each target under similar conditions, it is often appropriate to test the hypothesis that the mean ballistic limits of two or more materials are equal. Assuming that the ballistic limit is a normally distributed random variable, the test hypothesis becomes a simple "t" test. If the hypothesis is rejected, it is concluded that there is a significant difference in the ballistic limits of the two materials. If more than two materials are to be compared, analysis of variance techniques can be used to test the hypothesis.

The probability of penetration as a function of striking velocity is assumed to be described by the cumulative normal distribution, the mean of which is identical to the V50 ballistic limit. The Langlie test method and the up-and-down method provide a way of estimating the mean (μ) and standard deviation (σ) as well as their standard errors $\sigma_{\hat{\mu}}$ and $\sigma_{\hat{\sigma}}$.

$$\sigma_{\hat{\mu}} \doteq \frac{2.5}{n}\,\sigma$$

(At Aberdeen Proving Ground a computer program, based upon the method of maximum likelihood, is available to make these determinations - ref. 4c, appendix.) If σ is known from earlier data, $\sigma_{\hat{\mu}}$ can be computed directly. When σ is not known, a method of obtaining an unbiased estimate of its value is provided in the computer program. To test the hypothesis that the ballistic limits of two materials are equal, the following test statistic is defined:

$$z = \frac{\hat{\mu}_1 - \hat{\mu}_2}{\sqrt{\sigma^2_{\hat{\mu}_1} + \sigma^2_{\hat{\mu}_2}}}$$

Since z is approximately normally distributed with a mean of zero and a standard deviation of one, standard techniques for testing hypotheses for normally distributed random variables can be used.

If the Probit method (at least 50 rounds) is used, the V50 ballistic limit and standard deviation are determined either by the use of reference 4e or by plotting data on a curve and picking off the desired measures of performance.

7. Determining V50 Ballistic Limit with Gun-Fired Fragments. Fragments to be fired are selected to be as close to the prescribed weight as possible, preferably within (±)2 to 3 percent, but not beyond (±)5 percent. The range of fragment weights that must realistically be tolerated within a given weight category is a factor that tends to promote a large zone of mixed results during the determination of a V50 ballistic limit (see TOP 2-2-710). An even more significant factor in this regard is that the wide variety of shapes, hardness patterns, and impact orientations that are possible with randomly selected fragments within the same weight category will result in great variations in the penetrating efficiency of the different fragments. Thus, within the constraints of a typical test program, the V50 ballistic limit determination can, at best, only be considered a fair approximation. The wide variations in the attacking missile cause a considerable amount of data scatter. (This is the primary reason that the methodology of paragraph 6 is often preferred over shooting actual fragments.)

Velocity measurements are made with lumiline screens or break screens as described in paragraph 5.2.1, except that measurement of residual velocities behind the target is not required. The facilities required are the same as those in paragraph 5.2.2.

To determine the V50 ballistic limits, the up-and-down firing technique is usually employed (TOP 2-2-710) as described in paragraph 6.2.3. While it is preferable to average 10 rounds, fewer rounds may be used if the test program is limited (see TOP 2-2-710).

8. Determining V50 Ballistic Limit with Small Arms Projectiles. Occasionally there is a requirement to evaluate the resistance to penetration of body armor by small arms projectiles fired at relatively low velocities. The same up-and-down firing technique described in 6.2.3 above and in TOP 2-2-710 is used.

9. Environmental Conditioning. The properties of some body armor materials are affected by various climatic conditions, particularly high and low temperatures and high humidity. Thus, in addition to tests of body armor under standard ambient conditions (59° to 95° F, 15° to 35° C), there may be a requirement to test body armor under certain severe conditions. The extreme conditions usually are specified; if not, storage temperatures will conform to those of AR 70-38 followed by ballistic testing at somewhat more moderate temperatures that take into account the moderating effect of the human body for which the armor is designed. A humidity exposure, when required, is performed in accordance with TOP/MTP 4-2-820, and the ballistic test conducted while the material is still

exposed. Conditions of exposure related to the ballistic test will be consistent with those for basic tests of body armor (TOP/MTP 10-2-206).

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APPENDIX
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